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FOREST SERVICE, U.S. DEPT. OF AGRICULTURE, 6816 MARKET STREET, UPPER DARBY, PA. 19082

THE RELATIONSHIP BETWEEN SAP-FLOW RATE AND SAP VOLUME IN DORMANT SUGAR MAPLES

Abstract.—Sap-flow rate is closely correlated with the sap volume produced by dormant sugar maple trees *(Acer saccharum* Marsh.) and could be used in making phenotypic selections of trees for superior sap production.

The selection of sugar maple trees for superior sap production is important in the development of superior sap-producing genotypes. Despite ample evidence of between-tree variability, there is no practical way of making the mass sap-volume measurements necessary for selection of superior phenotypes.

Researchers in sap-flow experiments use two methods for making sap-volume measurements. In one method the sap produced by trees during the sugaring season is collected in large drums. In the second — and more sophisticated way — the sap is collected and measured in tipping buckets. In this method, electricity must be available to operate mercury switches and recording instruments. But in either method, measurements can be made on only a few trees.

For a selection program to be effective, it is necessary to have measurements on large numbers of trees over a wide area. To carry out a project of this magnitude for selecting superior sap-producing phenotypes, we need a faster method for determining sap production. Such a method would depend on finding a character that could be measured rapidly and would satisfactorily reflect the total sap volume produced by the tree.

Sap-flow rate can be measured quickly and easily, and it is closely associated with the total volume of sap produced by sugar maple trees. We found this by studying the relationship between sap-flow rate and total sap volume produced by individual trees during the maple sugaring season.

Background

Sap flow in dormant sugar maples is a function of changes in temperature *(Jones et al. 1903)*. Warm days and freezing nights provide ideal sugaring conditions by creating a pumping action at the taphole of the tree. Cold nights induce a negative pressure within the tree, during which moisture is absorbed through the roots. Warm days provide a positive pressure, forcing the sap from the tree.

Twig temperatures have been reported to be more closely related to sap flow than temperatures in the xylem or inner bark *(Marvin and Erickson 1956)*. Sap production was found to be associated with the crown and stem size of trees *(Moore et al. 1951)*. Trask and Ward *(1967)* reported that 70 percent of the variation in sap yield between trees they studied could be assigned to height and

diameter. Data from a sap-flow study by Jones et al. *(1903)* indicated that sap volumes of trees may fluctuate from year-to-year.

Our own observations, made over a 7-year period on 20 trees, have shown that trees with high sap-volume production are consistent in their performance rankings from year-to-year.

Materials and Methods

Sixty trees were selected for study in two relatively open sugar maple groves known as the Mitchell and Powell sugarbushes. These sugarbushes are located within 3 miles of each other on the eastern edge of Chittenden County, Vermont.

In general, the trees in both sugarbushes are widely spaced. Many of them have crowns that are open on two or more sides. The trees range from 13 to 39 inches in d.b.h. and from 57 to 90 feet in height.

All trees were tapped to a depth of 2½ inches. A 250-milligram paraformaldehyde pellet was placed in each taphole before inserting the spile and attaching the tubing, to retard bacterial growth that might lead to plugging of the taphole. Plastic spiles and tubing were used to conduct the sap from the trees to 20-gallon covered plastic containers (fig. 1). Graduated cylinders were used to collect sap for flow-rate measurements. Time intervals were determined by stopwatch.

Figure 1.—Left, sap-flow rate was measured with a stopwatch and graduated cylinder. Right, sap volume was measured to the nearest ½ liter.

Two groups of 20 trees each were selected for study in the Mitchell sugarbush. The trees in one group were tapped with only one hole, while the trees in the second group were multi-tapped, each tree receiving the number of taps recommended for its respective diameter, according to Willits *(1965)* as follows:

Tree d.b.h. (inches)	*Tapholes (number)*
Under 10	0
10-15	1
15-19	2
20-24	3
25 and over	4

Two groups of 10 trees each were selected in the Powell sugarbush and were tapped in the same manner as those in the Mitchell sugarbush.

All trees were tapped 4½ feet above the ground, during the latter part of February. Trees that were scheduled for only one taphole were tapped on the south face of the stem. On multi-tapped trees, the first taphole was made on the south face; other tapholes were drilled on the stem faces at the other cardinal points of the compass. All flow-rate measurements were made at the south-facing taphole of each tree on days when the sap was running freely.

Results

Sap flow rates of sugar maple trees showed a high degree of association among themselves and were highly correlated with the volume of sap produced.

Sap-flow rate.—One measure of the association of sap-flow rates may be expressed by W, the coefficient of concordance *(Kendall 1955, Segal 1956)*, in which W is computed from m rankings of n objects. Complete agreement among the rankings would result in W = 1; a complete lack of agreement would result in W = 0.

If the mean value of Spearman's rank correlation coefficient *(Spearman 1904)* is written as $\bar{r}_s$, then

$\bar{r}_s = (mW-1)/(m-1)$

Under the hypothesis that the m rankings are mutually independent, $X^2_r = m(n-1)W$ and has an X^2 distribution with $(n-1)$ degrees of freedom. The values of W, r_s and X^2_r are shown in table 1. The X^2_r values for the single- and multi-tapped trees in both the Mitchell and Powell sugarbushes were found to be highly significant, and they indicate a high degree of agreement among flow rates.

The mean of the rank correlations (r_s), when compared with the mean of the product-moment correlations (r_p), measured on an interval scale, showed that the correlations are higher than those measured on an ordinal scale. The product-moment correlations were

Table 1.—*Coefficients of association among the sap-flow rates for single- and multi-tapped trees in the Mitchell and Powell sugarbushes*

Correlation measure	Mitchell sugarbush		Powell sugarbush	
	Single tap[1]	Multiple taps[1]	Single tap[2]	Multiple taps[2]
Coefficient of concordance (W)	0.68	0.67	0.90	0.66
$X^2_r = m\ (n-1)W$	103.6**	102.1**	40.3**	29.88**
Mean Spearman's rank correlation ($\bar{r}_s$)	.64	.63	.87	.58
Mean product-moment correlation ($\bar{r}_p$)	.69	.64	.88	.79

[1] m = 8 sap-flow measurements; n = 20 trees.
[2] m = 5 sap-flow measurements; n = 10 trees.
** Highly significant.

Table 2.—*Product-moment correlation (r_p) between sap-flow rate and sap volume for single- and multi-tapped trees in the Mitchell and Powell sugarbushes*

Date measured	Mitchell sugarbush		Powell sugarbush	
	Single tap[1]	Multiple taps[1]	Single tap[2]	Multiple taps[2]
March 28	0.64	0.71	—	—
29	.59	.82	—	—
31	.64	.15	0.73	0.78
April 1	.85	.46	.88	.88
5	.94	.42	.89	.87
6	.93	.48	.92	.80
9	.93	.52	.96	.43
11	.89	.67	—	—
Correlation of mean sap-flow rate and sap volume				
	0.93**	0.55*	0.92**	0.81**

[1] n = 20 trees.
[2] n = 10 trees.
* Significant.
** Highly significant.

lower for the Mitchell sugarbush than for the Powell sugarbush, but the lowest rank correlation was found in the multi-tapped trees in the Powell sugarbush (0.58, table 1). The product-moment correlation analysis confirmed the results of the rank analysis and verified the close agreement among flow-rate measurements taken on individual trees.

Sap volume and sap-flow rate.—A correlation analysis was run to determine the relationship between the sap volume produced and the rate of sap flow. In the analysis we calculated (1) the product-moment correlations (r_p) between individual flow rates and sap volumes, and (2) the correlations between mean flow rates and sap volumes (table 2).

Sap-flow rates and sap volumes were highly correlated for the single-tapped trees in the Mitchell sugarbush and the single- and multi-tapped trees in the Powell sugarbush. In general, there was a closer agreement between flow rates and sap volumes for single-tapped trees than for multi-tapped trees, particularly in the Mitchell sugarbush. Although there was a low correlation (0.15) in one set of measurements among the multi-tapped trees in the Mitchell bush, the correlation (0.55) between the mean sap-flow rate and the sap volume produced was significant. This showed that several measurements are necessary to identify trees with high sap-flow rates.

Conclusions

Our conclusions:

- There is a high degree of association between the sap flow rate and the total sap volume produced by individual dormant sugar maple trees during the maple sugaring season.
- Though it is possible to distinguish superior sap-producing phenotypes by one sap-flow-rate measurement, final selections should be based on at least three measurements because of occasional deviations.
- In the final screening, each selected tree should be single-tapped, and the taphole should be made on the south face of the tree.
- Sap-flow rate can be incorporated successfully into a practical method for the selection of sugar maple trees for superior sap production.

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—WILLIAM J. GABRIEL
RUSSELL S. WALTERS
DONALD W. SEEGRIST

Northeastern Forest Experiment Station
Forest Service, U. S. Department of Agriculture

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